AY 2005-2006
Industry Study

Final Report
Strategic Materials

The Industrial College of the Armed Forces
National Defense University
Fort McNair, Washington, D.C. 20319-5062

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2006**	2. REPORT TYPE	3. DATES COVERED **00-00-2006 to 00-00-2006**
4. TITLE AND SUBTITLE **AY 2005-2006 Industry Study Strategic Materials**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **The Industrial College of the Armed Forces,National Defense University,Fort McNair,Washington,DC,20319-5062**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**29**	

STRATEGIC MATERIALS 2006

ABSTRACT: Some materials possess greater value than others. Materials that provide essential support for the nation's economic viability or enable critical military capabilities warrant special attention in security studies. Government influence can affect the development, adaptation, and use of these materials. This report explores and analyzes relevant aspects of the strategic materials industry, focusing particularly on characteristics and trends that determine and shape the government's role. This study uncovers little evidence of market failures that warrant more assertive government intervention. However, efforts to improve government's involvement in this industry could help satisfy strategic needs and minimize distortion of free markets.

Lt Col Carl Buhler, US Air Force
LtCol Adrian Burke, US Marine Corps
COL Kirk Davis, US Army
Ms. Michelle Gerhard, National Security Agency
Ms. Valerie Heil, Defense Security Service
Mr. Richard Hulse, Dept of the Navy
Mr. Ralph Kwong, Dept of State
COL Michael Mahoney, US Army
CDR Scott Moran, US Navy
CAPT Michael Peek, US Navy
Mr. Eric Pitt, Dept of the Navy
CDR Gregg Sears, US Navy
Lt Col Mark Williams, US Air Force

Dr. Sylvia Babus, Faculty
Dr. Maureen Crandall, Faculty
Mr. Bill Jones, Faculty

PLACES VISITED

Domestic

Naval Research Laboratory (NRL), Institute for Nanoscience, Washington, DC
United States Geological Survey (USGS), Minerals Information Team, Reston, VA
Army Research Laboratory (ARL), Weapons and Materials Research Directorate, Aberdeen, MD
The Center for Composite Materials (CCM), University of Delaware, Newark, DE
Air Force Research Laboratory (AFRL), Materials and Manufacturing Directorate, Dayton, OH
Cooley Group Engineered Membranes, Pawtucket, RI
Saint-Gobain Advanced Ceramics and Plastics Research and Development Center, Northboro, MA
Hyperion Catalysis International, Cambridge, MA
US Army Soldier Systems Center, Natick, MA
Foster-Miller, Inc., Waltham, MA
Triton Systems, Chelmsford, MA
Dynamet Technology Inc., Burlington MA
Massachusetts Institute of Technology, Institute for Soldier Nanotechnologies, Cambridge, MA

International

MTU Aero Engines, Munich, Germany
Technical University Munich, Garching, Germany
EADS Corporate Research Center, Materials Research Division, Ottobrunn, Germany
Minatec Consortium, including CEA-Leti, Grenoble, France
Tronic’s Microsystems, Crolles, France
Office National d’Etudes et de Recherches Aérospatiales (ONERA), Chatillon, France
Dassault Systèmes, Suresnes, France
NP Aerospace, Ltd., Coventry, England
Jaguar Cars, Ltd., Castle Bromwich, England

Strategic Materials Industry Study 2006

Drawing generalizations from a field as diverse as materials is difficult. Some surveys seek to structure the field by categorizing similar material properties or processing methods to form groups such as metals, ceramics, composites, polymers, aggregates and nano-materials. However, such an approach fails to identify the key elements that make certain materials important for national security. Instead, a category of "strategic materials" can be defined to include those that support the nation's economic viability or enable critical military capabilities. A close study of the industry that produces strategic materials provides a foundation upon which policymakers can build a strategy to adapt and use materials to meet the nation's most pressing requirements.

Strategic materials: Bounding an amorphous industry

Materials with strategic importance possess properties essential for defense applications or the nation's economic security. Properly developed and integrated, materials enhance a wide variety of militarily useful properties such as strength, survivability and lethality. They may also introduce efficiencies such as self-diagnosis, self-healing and multi-functionality that increase system reliability and decrease lifecycle costs. Beyond their military value, some materials have demonstrated strategic economic importance due to factors such as scarcity, industrial base needs and potential to influence the nation's future competitiveness. Access to these materials as well as production and processing facilities can be critical for a variety of security and economic objectives.

Establishing general conditions that indicate strategic value in materials and materials-related processes provides important background for analyzing the industry that develops and provides them. However, these conditions are subject to modification as new global economic, technology and security trends emerge. During the Cold War, the Office of Technology Assessment (1985) described a strategic material as "one for which the quantity required for essential civilian and military uses exceeds the reasonably secure domestic and foreign supplies, and for which acceptable substitutes are not available within a reasonable period of time" (p. 11). However, new perspectives on strategic materials have developed since that era. This evolution is apparent in a statement by former Deputy Secretary of Defense John Hamre (2000), who described the notion of a requirement for the nation to "be prepared to fight by itself and be prepared to supply itself during any conflict from within the domestic industrial base" as an "obsolete paradigm" (p. 9).

Some academic writings on material reflect this new paradigm as well. Economist David DeNoon (2001) summarizes this contemporary viewpoint on materials' strategic importance:

> As the United States has shifted from an industrial to a service economy, the livelihood of its citizens depends less on imported raw materials than it did at the time of the Paley Commission. The United States is less worried about chrome from East Africa or copper from Chile than it once was. Also, as materials science has become more sophisticated, it has yielded a host of synthetic products that can directly substitute for natural ones or prior manufactured ones (p. 249).

Given these observations and the power of global economic forces, it is reasonable to ask what materials or processes today could be considered strategic. Equally important is an assessment of existing – or potential – market failures that might require government

intervention. Both of these perspectives lead to deeper questions regarding the appropriate role of government and the extent of intervention required to meet strategic needs.

Industry analysis of strategic materials: Overview and discussion of methodology

Selecting an approach to answer these questions is critical for analyzing this industry. Harvard Business School Professor Michael Porter's (1980) method of examining an industry's evolution through lifecycle stages provides a particularly relevant framework for the study of strategic materials.

Categorizing strategic materials through lifecycle stages helps cope with the industry's sheer diversity of issues. Analysis of any individual material can lead to specific observations that may not be indicative of larger trends. In contrast, within each stage of development – introduction (or breakthrough), growth, and maturity – commonalities exist across a variety of materials categories. Categorizing strategic materials by these lifecycle stages becomes especially useful in attempting to determine appropriate roles for government activity.

Some materials markets are relatively mature and employ processing techniques that are decades or centuries old. The aluminum and steel industries provide illustrative examples. While innovation continually reshapes these mature markets, companies more typically seek cost and service improvements to gain competitive advantage (Porter, 1980). In the face of stiff international competition, American participants in these industries have sometimes sought protection by arguing for active government incentives or trade restrictions.

Less mature materials are often in a growth stage of product lifecycle. Many such materials possess inherent strategic value due to advanced properties or necessity for security applications. Porter (1980) notes that companies seek to gain competitive advantage in a growth stage through product improvement as well as technical and performance differentiation. Examples of strategic materials that exhibit these characteristics include advanced composites, super-alloys, and specialized materials containing rare earth elements (REEs). While access to some raw materials is sometimes worrisome for growth stage materials markets, other concerns such as technology transition and cultural attachment to legacy materials provide common themes in this stage.

Many materials scientists hold even greater hopes for undiscovered strategic materials of the future. However, significant forces sometimes act against the introduction of entirely new materials. Disciplines such as nanotechnology, micro-electro mechanical systems (MEMS) and biomimetics seek to provide order-of-magnitude improvements in materials as well as unimaginable future capabilities. Porter (1980) emphasizes that early lifecycle stage ventures are fraught with high risk, high marketing costs and development difficulties requiring substantial R&D and engineering. Overcoming these challenges in emerging materials science fields sometimes requires more active government involvement.

This report examines each stage in turn using a common methodology. We begin by describing current conditions to provide context. This is followed by examples of typical challenges faced by industry participants in that stage. Expectations for the future are detailed in a discussion of the industry's outlook, with an eye to business strategies that are appropriate to achieve competitive advantage. Finally, the analysis for each stage concludes with a discussion of appropriate government roles and policy recommendations.

While this methodology helps identify issues and concerns for each lifecycle stage, certain themes cut across these traditional categories. Several of these cross-cutting themes are

detailed in short essays covering legal issues concerning materials, innovation in materials, and materials substitutability.

This examination of strategic materials, within and across lifecycle stages, generally reveals an industry that is well positioned to support the nation's critical needs. However, efforts to streamline and clarify government's roles in this industry could improve the nation's economic and security posture. The major themes that are identified in the body of this report are briefly revisited in a conclusion that summarizes recommendations for improved government interactions with the materials industry. While this study found little evidence of market failures that would warrant significant policy shifts, useful insights emerge that should assist decision makers shaping government roles in this important industry.

Strategic Materials in Mature Markets

Current conditions

Twentieth century global conflicts required massive surges in manufacturing capacity to build-up military weapons, vehicles and supporting equipment stocks. For example, in 1944 alone America's industrial base produced nearly 100,000 aircraft, or more than 16 times the 1939 production, to meet war requirements (Kennedy, 1987/1989). During such a mobilization, the industrial base strained to provide sufficient material to accommodate needs. Difficulties experienced during mobilization led many to the conclusion that domestically controlled access to and production of commodity-like materials such as steel and aluminum were strategic necessities.

However, both the changed security environment and the world economic market for mature materials warrant reconsideration of this paradigm. Post cold-war military experiences in a variety of theaters have emphasized rapid and flexible action in asymmetric engagements rather than large-scale campaigns. Thus, plans to conduct limited campaigns using pre-existing inventories have largely superseded the 20th century model of national mobilization with rationing of strategic materials. This philosophical shift has changed formerly accepted truths regarding the strategic value inherent in commodity-like materials. Where the military value of materials such as steel and aluminum assumed primary importance in the past, considerations of economic strategic value now carry far greater influence.

This shift also reflects structural and accelerating changes within economic markets for mature materials as the curtain fell on the 20th century. During this transition, some segments of American industry increasingly turned to overseas markets to meet material needs when economic factors favored offshore supply or production. While this process of globalization benefited buyers of some materials, many domestic materials manufacturers lamented the associated depression of prices for their commodities and lobbied for protection, sometimes claiming a "strategic necessity." Some of these efforts succeeded, as illustrated by substantial tariffs placed on imported steel (Bush, 2002).

More recently, requests for government support of mature strategic materials have subsided as prices have rebounded. The current steel market illustrates this point, as significant price inflation over the last few years has buoyed domestic producers (AISI, 2005). Following decades of stagnant (or negative) returns, these significant price increases have enabled the domestic steel industry to recover and modernize. However, continuation of this trend is not assured. In particular, rapidly expanding steel production capacity, especially in China, makes

prediction of long-term industry health very difficult. This volatility hints at the difficulty of anticipating future trends, one of many problems faced by materials producers.

Challenges

A review of issues that commonly affect mature markets helps frame the additional problems faced by mature materials firms. Porter (1980) enumerates specific patterns found among industries entering the maturity lifecycle stage such as increasing competition for market share, greater emphasis on cost and service, increasing international competition and declining profits. Mature materials firms face particularly difficult concerns in maintaining competitive advantage with international competition due to uneven worldwide costs of labor, capital and energy. Participants also struggle to accurately estimate future capacity requirements and recapitalize obsolete production facilities. A more complete description of each of these challenges follows below.

Maintaining competitive advantage. Companies in a mature industry will normally seek to gain advantages by controlling costs and improving service more effectively than their competitors. Achieving these objectives is somewhat complicated given the international competition in mature materials markets. Domestic producers complain of unfair international competition due to uneven trade incentives, inconsistent environmental protection standards and wide differences in labor and overhead costs.

Increases in energy costs have been particularly tough for domestic materials producers. In the 1960s, the U.S. produced over half of the world's aluminum. The U.S. enjoys less than half that share today. While many factors contributed to this result, much of this decrease can be attributed to domestic energy costs, which outstripped the costs of some international competitors. The energy-intensive steel industry faces a similar problem. Strikingly, U.S. aluminum producers with access to hydroelectric plants have sold electricity – instead of aluminum – when returns on energy exceeded those available from smelting operations (*N.Y. Times*, 2000, December 27).

Continued increases in energy costs might eventually threaten the viability of domestic materials producers. Long-term survival will likely require innovative solutions to maintain competitive advantage, such as increased recycling (which generally requires far less energy). If U.S. companies find themselves unable to compete successfully, developing policies that support some level of domestic materials production without introducing counterproductive market distortions would challenge policymakers.

Uncertain demand. Markets in commodity-like materials have experienced enormous recent growth as developing countries have begun to industrialize. Many materials producers, especially in developing nations, have expanded production capacity in anticipation of growing demand. Buyers, perhaps anticipating potential surges in demand, have taken actions to mitigate potential shortages. For example, Airbus recently signed $1.4B of long-term contracts to provide sufficient titanium for expected airline orders through 2015 (Michaels, 2006).

Proportionate growth in both supply and demand of any commodity is not problematic. However, American manufacturers express concern that uncertain demand may produce market imbalances. Firms point to the potential for volatility in both production and consumption of materials in China as potentially destabilizing for world markets. Similar worldwide shifts in steel production and demand resulted in the 2002 steel tariffs.

Domestic producers of mature materials have difficulty projecting profitability given the uncertain future demand and the possibility of excess capacity around the globe. A significant

decrease in demand could depress prices to the point that the continued viability of domestic materials production becomes questionable. Should that occur, the U.S. would have to weigh the potential benefits of maintaining domestic sources for commodity-like materials against the costs of intervention.

Recapitalizing aging production infrastructure. Domestic production facilities for some materials are not economically feasible to replace or modernize. Economic principles show that attracting capital is difficult without solid projections of positive return on investment. Production capacity for commodity-like materials is effectively frozen without a compelling business case. Accordingly, no new U.S. aluminum smelters have been built in the last 30 years. A similar problem exists for integrated steel mills, which continue to be retired as they reach obsolescence. While mini-mill steel production has generally offset decreased output from integrated mills, these facilities reprocess steel from scrap and would have difficulty scaling-up production to accommodate substantial increases in demand.

As facilities continue to age without hope for replacement, the nation faces the possibility of losing production capability for some mature-stage materials. Furthermore, the use of outdated facilities and processes is generally inefficient, a poor strategy for a market that rewards low cost producers. Although no government intervention is currently necessary to reverse declining recapitalization of mature material production capacity, the government must consider the loss of domestic production capacity in its short and long term planning.

Outlook

Globalization trends coupled with present challenges in mature materials markets imply a decreasing emphasis on assured access to commodity-like materials with an increased focus on issues of economic competitiveness in international materials markets. As a result, assessing the economic value of a particular material assumes greater importance. Recycling and reuse of existing material stocks will become increasingly important to reduce negative externalities associated with material production and to offset increased production costs.

Experience indicates a tendency for increased international competition to result in government protection of domestic industry. In these cases, care is required to weigh the costs of intervention against the perceived benefits. Claims of strategic value for particular materials are relatively easy to make and often resonate with political stakeholders. However, cases where compelling evidence demonstrates a strategic gap are truly exceptional.

A significant philosophical shift regarding the nation's stockpile of strategic and critical materials illustrates this point. Established by the Strategic and Critical Materials Stock Piling Act of 1939, the strategic stockpile once contained materials worth over $16B (Echternacht, 2005). However, as time passed, defense needs and stockpile contents diverged. Today, DoD calculations fail to identify the need to stockpile *any* material. The existing stockpile is thus undergoing liquidation of all contents except for three materials that fill unique strategic niches: beryllium metal (hot-pressed powder), mica and quartz crystal (DoD, 2006). The willingness to forgo the insurance provided by a stockpile indicates decreased concern about access and scarcity issues and higher standards for declaring a material "strategic."

In sum, while the outlook for mature materials markets is uncertain, calls for aggressive government involvement in these markets warrant healthy skepticism. Market forces will likely drive companies to seek additional efficiencies in offshore facilities and international partnerships. Surviving and thriving among these forces will require participants to carry out effective cost leadership strategies. Porter (1980) establishes critical elements of a low cost

strategy such as efficient organization, management control, and minimization of overhead. American industry is generally well positioned to meet the nation's strategic needs for mature materials, but the government can still play an important supporting role in this sector.

Government role

The provision of a suitable environment for the materials industry to flexibly adapt to current trends and overcome structural challenges should form the basis of government's involvement. However, government efforts must judiciously balance current and future needs to ensure that stakeholder pressure does not result in counterproductive policy decisions. While efforts to support inefficiencies are sometimes necessary for strategic needs, such decisions should acknowledge and accept both tangible and intangible costs of government intervention.

American economic strength rests upon a foundation of free markets that "allocate resources to their highest-valued uses, avoid waste, prevent shortages, and foster innovation" (CEA, 2005, p. 149). Such an environment has produced unparalleled growth that could never have been anticipated or planned by bureaucrats. However, government support for investment and improvement in areas of strategic importance can be critical for national interests. Some areas of intervention come with few costs, such as continued efforts to reduce international trade barriers. Additionally, greater collaboration between government and industry could improve anticipation of supply and demand trends in some materials markets. In selected areas where more active government involvement is required to meet strategic needs, intervention might include targeted incentives or active support, but government efforts should seek minimally intrusive roles to avoid unnecessary distortion of market forces.

Strategic Materials in Growth Markets: Leveraging Advanced Properties

Current conditions

New materials and their successful integration into government and commercial products have provided the U.S. with unrivaled military capabilities and enhanced the nation's economic security. A wide variety of materials with advanced properties satisfy critical military capability needs, yet lack economically viable commercial applications. Increasing expectations for militarily relevant materials properties coupled with extensive investment has fueled significant expansion within this family of materials. Commercial industry interests also contribute to the development of materials with advanced properties in cases where performance advantages outweigh potential switching and supply costs. While advanced materials with broad commercial and military utility will likely mature to resemble commodities, defense-specific advanced materials may need special attention from the government to promote and ensure their availability.

Materials with advanced properties usually fall into two general categories:

1. Man-made materials developed with particular properties in mind, for example, super-alloys, composites and ceramics, and
2. Naturally occurring materials with utility in emerging high performance applications such as rare earth elements (REEs) and beryllium.

As materials scientists learn more about why these materials behave the way they do, they are better able to use the materials' unique properties in applications that require exceptional performance. Super-alloys, for example, combine high strength with good low-temperature ductility and excellent surface stability; they were first used in aircraft turbine engines that

required high performance at elevated temperatures (Schafrik & Sprague, 2004). Advanced composites have emerged in an analogous fashion. Composite materials are increasingly substituted for more mature materials in many applications because they offer superior design flexibility, strength-to-weight ratio, corrosion resistance and durability. Beryllium provides a final example. Beryllium is nature's lightest rigid metal. It has high thermal conductivity and is resistant to acid corrosion. These properties make beryllium especially well suited for high-end defense applications such as inertial guidance systems, turbine rotor blades, warheads for nuclear weapons and rocket engine liners.

Challenges

While materials with advanced properties demonstrate enormous promise for military and commercial applications, bringing a new material into mainstream use is difficult. Competing R&D priorities, industry and DoD acceptance, and the potential interruption of access to materials feedstock are among the most significant barriers new materials must overcome if they are to achieve wider use.

Transition of promising research and development. Expanding knowledge of materials science coupled with the ability to engineer materials properties has produced astounding technological advances. But industry must be convinced that potential benefits of new materials outweigh the costs and risks associated with developing and switching to them. DoD, which relies on technological superiority for military advantage, must grapple with ways to transition the most relevant materials-related R&D to fielded defense systems.

Reductions in future defense procurements will intensify debates over the introduction of new materials. These decisions must weigh the necessity of improved capabilities against acquisition costs. Favoring mature materials to reduce program costs may limit opportunities to realize potential technological and economic improvements through advanced materials. These complex tradeoffs must be considered carefully by industry, academia and government stakeholders to ensure the most appropriate technologies are integrated into new systems.

Though development investments may be shrinking, ongoing advances in modeling and simulation (M&S) could allow for more efficient application of these dollars. Computer-aided modeling can save large amounts of test and development time when compared to trial-and-error methods. Actual use of M&S has revolutionized efforts to develop new materials at DoD laboratories (AFRL, 2005).

Custom designing "a material … in order to obtain a desired set of properties suitable for a given application" greatly reduces uncertainty about the properties of a material before it is manufactured (MPG, 2001, p. 12). The NRC (2004) concurs that such a custom-design approach could greatly facilitate the introduction of new materials for DoD applications.

Acceptance. Design engineers typically choose materials that offer the most promising combination of cost, performance, reliability and manufacturability. Historically, certain materials such as steel and aluminum have enjoyed wide use because they have served designers and end users well.

Fielding new materials and technologies takes significant time; typically, more than 10 years is required to mature a material or processing technique from research to commercial application (NRC, 2004). Often, new manufacturing processes must be developed to transition a new material or processing technique from the laboratory to the production line. New manufacturing equipment or facilities may also be required. Additionally, workers need training on new manufacturing processes and product designs often require alterations to take

full advantage of a new material's properties. Accordingly, industry avoids new materials due to the potential for negative consequences and delays they might introduce.

Engineers, trained to design using mature materials and well-documented processes, may be the biggest obstacle to the introduction of advanced materials. For generations, engineers have designed their products using handbooks that catalog fundamental material properties, such as strength, stiffness, and elasticity. This approach allows engineers to predict the performance of structures in a relatively straightforward manner. More complex physical properties and the lack of accepted performance databases for advanced materials make similar predictions far more complicated. Only when engineers achieve greater confidence in a new material's properties and/or manufacturability will it receive wide acceptance.

Access to raw materials. Predictable, sustained access to materials feedstock is important to commercial and defense manufacturers. If feedstock essential to the production of certain advanced materials is unavailable domestically, demand for these materials for critical military applications could create a foreign dependency that might jeopardize our security.

Frequently cited materials with limited access are a group of rare earth elements (REEs) which are useful in both the military and commercial electronics industries. U.S. companies imported 98.3 percent of rare earth compounds consumed in 2004 (Hedrick, 2004). Currently, only China and Russia produce these raw rare earth ores. Moreover, China currently dominates the worldwide production of the rare earths with over 93 percent of the market (USGS, 2006). Given China's dominance, it is reasonable to ask if U.S. buyers' access to rare earths might be subject to changes in China's foreign policy.

However, the scarcity issue associated with REEs appears to be exceptional. A RAND report on globalization issues noted that in eight large DoD programs the "value of parts, components, and materials obtained from foreign sources accounted for less than two percent" of the total value" (Lorell et al, 2002, p. 67). While understanding a potential material-access problem is important, past U.S. government interventions to hedge against strategic shortages, such as the national defense stockpile and the strategic petroleum reserve, have generally been ineffective in accomplishing their intended goals (Taylor & Van Doren, 2005; GAO, 2001).

Outlook

Industry will continue to use innovative, engineered materials to fulfill unique military requirements and meet selected commercial needs. In contrast to the commodity-like nature of more mature materials, the production of these materials frequently occurs in relatively limited quantities, an important factor in explaining industry's reluctance to retool or invest in new infrastructure. While wider use of these materials for large-scale commercial applications can offer economies of scale, industry must first conclude that potential benefits in lower manufacturing costs or expanded market share exceed switching costs.

The nation will continue to rely on external sources for some materials. While this dependence is undesirable for a few critical materials, overcautious product designers and decision makers can over-emphasize potential access issues and thus discourage the use of advanced materials. Objectively balancing the costs and benefits of using scarce (or difficult to access) materials will continue to pose dilemmas for policymakers, especially as the nation's stockpile of strategic materials is sold off.

Firms in growth materials markets will continue to require a differentiation strategy to compete successfully. While the particular approach used to differentiate a material product or process will vary, Porter (1980) emphasizes that creating a unique feature or property is

fundamental for differentiation. Because the DoD often defines novel requirements for materials, government involvement in this sector will continue to strongly influence the evolution of growth materials markets.

Government role

The U.S. government has played an influential role in bringing about materials improvements through efforts to meet specific needs. In the past, the combination of high expectations and substantial acquisition budgets produced tremendously useful materials, many of which spilled over into commercial markets. In an environment where powerful pressure exists to reduce development and procurement budgets, efficient and innovative solutions will be instrumental for continued transition of advanced technologies into new materials.

Some promising efforts are underway to facilitate technology transition of advanced materials. Materials scientists at the Army Research Lab (ARL) are attempting to refine and standardize a materials readiness level (MRLs) system to lend objectivity to technology maturity assessments, thereby improving technology transition efforts (McNight, 2006). Similarly, the Air Force Research Lab (AFRL) Accelerated Insertion of Materials (AIM) program could provide a foundational model for collaborative efforts between the government, academia, and industry. AIM seeks to provide a mechanism for advancing the state of materials research and encouraging the transition of new materials from the laboratory to the battlefield and commercial marketplace.

Commercial transition of advanced materials becomes especially important when considering strategic value through both military and economic lenses. While a technologically superior material can provide obvious military advantages, the economic value of such a development should not be underestimated. In fact, the strategic economic impact of advanced materials can be enormous, as “technological progress is responsible for up to one-half the growth of the U.S. economy, and is one principal driving force in long-term growth and increases in living standards” (Schacht, 2005). Government’s principal roles in advanced materials markets will revolve around developing strategic materials that lack a viable commercial market. However, creating a supportive environment for commercial transition of these advanced materials can significantly improve their strategic value to the nation.

Introduction of New Strategic Materials: The Development of Revolutionary Properties

Current conditions

Strategic planning documents express great hope for the use of advanced technologies in new equipment (CJCS, 2004; OSD, 2005; OSD 2006). Experience indicates that many of these improvements would emerge from the use of revolutionary materials in emerging applications. Because materials provide almost limitless potential future improvements, stakeholders in government and industry pursue their development to provide for security needs and for profit. Materials scientists facilitate these efforts by performing a wide range of basic and applied research throughout academia. While most work on emerging materials may have limited short-term applicability, new materials and materials processes warrant continued attention to fulfill the nation’s long-term strategic requirements.

Our world – including the economic and security environments – has been shaped by farsighted investments in emerging materials. For example, giant magnetoresistance (GMR) hard drives used in modern computers store information in nanometer-scale magnetic material

layers providing data storage capacities that would have been unimaginable just a decade ago. Clearly, technologies such as GMR strengthen America's economic and military competitiveness. Because ongoing research in nanotechnology and many other visionary materials disciplines such as transparent armor (single-crystal sapphire) and exotic special-purpose alloys should produce similar quantum leaps in future capabilities, a discussion of the source of emerging materials technologies is critical for analysis of this industry.

Promising materials solutions are often the culmination of numerous farsighted and wide-ranging research efforts. In the case of GMR, centuries of research in electromagnetism laid the foundation for today's capabilities. Development of research findings through studies of advanced manufacturing technologies, such as friction stir welding, cold spray deposition, and micro-manufacturing, are critical enablers for the introduction of promising materials in future industrial applications. Advanced modeling and simulation (M&S) techniques hold further promise to facilitate and accelerate the development and use of materials, such as emerging alloys, ceramics, and composites – especially as substitutes for conventional materials. Finally, significant investments in target disciplines, such as the National Nanotechnology Initiative's (NNI's) $228M 2006 budget for nano-materials R&D, are intended to open the door to unexplored frontiers in materials science (NNI, 2005, p. i). Robust research in these many areas makes the future look bright, but a variety of challenges must be overcome to unlock the potential of future materials.

Challenges

As previously discussed, ventures in breakthrough technologies face development difficulties that require substantial R&D and engineering. Within the materials industry, specific problems include long development cycles, funding support, stakeholder concerns and foreign competition. Overcoming these challenges merits greater government attention than typically required for more mature materials markets.

Lengthy development cycles. Fielding new technologies takes significant time; typically, more than 10 years is required to bring a material or processing technique from research to application (NRC, 2004). Such timeframes require long-term commitment of resources and attention. Maintaining focus for materials science is especially challenging in an environment where pressures to reduce risk and accelerate development time are mounting within the defense acquisition community and among external stakeholders (GAO, 2004).

There is a delicate balance between efforts to meet long-term economic and security needs and short-term budget and political constraints. In general, short-term priorities tend to find favor as government budgets decline. Thus, maintaining stability in government-funded research for materials during periods of budget decline can be especially challenging given the extended timescales required for development.

Attracting private capital for long-term developments is even more difficult. For example, an independent research consulting company points out that despite $18B of government investment in nanotechnology, venture capitalists show an "almost total lack of interest" in this specialty, with a miniscule 0.14 percent of their funds in nanotech-related efforts (Cientifica, 2006, p .1). Carrying out a judicious investment strategy to ensure that short-term priorities do not dominate decision making in critical materials research areas will therefore continue to challenge the materials community.

Support for R&D. The decades-long maturation process required to insert a new material into an application makes government support for basic R&D especially important. Economists note that the demands of private industry and its focus on the bottom line make it difficult for it to sustain a long-term commitment to basic research. Therefore, government funding is necessary to provide early basic R&D as a "public good" (Baumol & Blinder, 2006, p. 314). However, government basic materials research funding is shrinking. Several studies document decreasing overall federal R&D investments as well as diminishing DoD involvement in materials engineering (Marshall, Coffey, Saalfeld & Colwell, 2004; Merrill, 2001). To cope with decreasing budgets, defense leaders and the R&D community must cooperate to identify the most pressing needs and most promising research programs.

While government R&D budgets do target specific goals, effective coordination and prioritization of these efforts to develop new materials is difficult. Innovative companies at the leading edge of technology often pursue funding for highly focused development through the Small Business Innovation Research (SBIR) program. Site visits to small companies across the spectrum of material communities demonstrated extensive SBIR participation. While programs like SBIR have enabled significant progress, company representatives lamented their instability and unpredictability in funding productive long-term research. Thus, coordination of research and its associated funding remains problematic for some cutting-edge materials firms.

Stakeholder concerns. Emerging material technologies often face significant resistance by stakeholders whose interests may be affected. Any number of factors may be at play, including political, cultural, military, industrial, labor, and non-governmental concerns. For example, concerns about the environmental, health and safety issues associated with nano-materials have shaken this fledgling discipline.

Because nanotechnology is an emerging science, the short and long-term health effects of exposure to nano-materials, such as carbon nanotubes, are unclear. However, initial studies indicate growing concerns and the need for government involvement (Mraz, 2005; Weiss, 2006a). In response, German government officials recently issued "the first health-related recall of a nanotechnology product, raising a potential public perception problem for the rapidly growing but still poorly understood field of science" (Weiss, 2006b, p. A02). The U.S. government has also responded, providing funding through the NNI to explore health, ethical, legal and societal implications of nano-materials.

While nanotechnology provides an example of constructive efforts to balance a broad spectrum of stakeholder concerns, interest groups have acted to prevent the emergence of other promising materials. Newcomers attempting to introduce substitute materials (including composites, ceramics, and specialized metals) complain of lobbying efforts directed against them from more established materials industry firms. The government should avoid selecting particular winners and losers in any industry, but addressing and balancing the concerns of competing stakeholders will continue to occupy the attention of American policymakers.

Foreign competition. Global competition in the emerging materials market will remain a significant challenge. Though America maintains a technology lead in some materials disciplines, it lags behind other countries in research, patent production and graduate school enrollment in a variety of material specialties (NRC, 2005). For example, investment in materials R&D established Japan as the undisputed leader in the aerospace-grade carbon fiber market. Similar trends in other breakthrough materials technologies overseas led the NRC (2005) to predict serious erosion in America's "lead in critical technologies" (p. 3).

Maintaining a technological lead in any materials science specialty will become increasingly difficult for the U.S. as globalization continues.

Outlook

Government, industry and academia will continue to push the technological envelope to develop breakthrough materials. While these efforts will certainly contribute to the economic and military power of the nation, policy makers should temper their expectations with an appreciation for difficulties that may stall the emergence of strategic advantages through materials science. Overcoming the challenges that face this sector of the materials industry will require focused efforts to realize the potential that technology can offer.

In the short term, pressures will likely intensify. Experts anticipate increasing foreign competition in materials science resulting from aggressive pursuit of materials research and advanced education (NRC, 2005). Furthermore, decreasing defense procurement budgets will likely require cuts in materials basic R&D and aggravate the existing problem of long development cycles for new materials.

Unfortunately, most of these short-term problems can create or exacerbate long-term ones. Lack of progress in emerging materials markets can serve to strengthen participants in more mature sectors. This development could reinforce unwillingness among stakeholders to accept risks associated with new materials and frustrate the efforts of those seeking to bring innovation to defense programs. Beyond the loss of potential military capabilities, the economic costs could be significant if the nation's engine of innovation decelerates.

Companies seeking competitive advantage in breakthrough materials markets require strategies that focus on specific areas of competency. To accomplish this, Porter (1980) recommends strategies centered almost exclusively on the targeted industry segment. To sustain such a narrow focus, government involvement may be necessary if defense requirements are to be met.

Government role

Ensuring the development of the next generation of materials will require dedicated government support. Experts in the materials field view DoD as the key organization to organize and fund materials research, recommending additional research into the discovery and characterization of materials with unique or substantially improved properties" (NRC, 2003, p. 2). Defense leaders acknowledge this critical role as "many emerging defense suppliers find it difficult to raise funds for military R&D and project opportunities" (DUSD(IP), 2003, p. B-8). While many stakeholders would welcome increased funding for advanced materials research, a more fiscally responsible initial step would prioritize research endeavors to ensure the nation's most important requirements are met.

Many government efforts already focus specifically on innovative research in materials specialties. These efforts support a wide variety of worthwhile research in materials science. However, individual agencies award many of these grants piecemeal. The result is a relatively uncoordinated research strategy. Greater collaboration between industry, government and academia could streamline these research efforts and ensure the most important projects receive government support. Cooperative efforts would help ensure that critical strategic needs are met more efficiently. Greater coordination could improve buy-in from key stakeholders and enhance competitive advantage throughout the domestic materials industry.

Essays on Cross-Cutting Issues in Strategic Materials

Factors that cut across lifecycle stages in the materials industry have significant policy impacts. The following essays explore three of these areas of interest: legal framework complexity, trends in innovation, and opportunities for substitution in the materials industry. Examination of these issues broadens the scope of this industry analysis.

Complexity of Legal Structures Governing Materials

A broad range of policy issues interweave themselves throughout the materials industry, and a complex legal structure has followed – with elements that both encourage and inhibit progress. While industry is primarily concerned with shareholder value, government's diverse concerns are expressed through laws, regulations and policies. Industries that produce or provide strategic materials are affected by a tapestry of concerns in areas such as foreign direct investment (FDI), off-shoring of production, industrial base sufficiency, access to suppliers, protection of jobs, patent and trade legislation, export controls and industrial security (GAO, 2005).

Ongoing tension between industry and government interests exists in many areas. For example, efforts to maintain a more robust industrial base could detract from other policy objectives. As laws and regulations evolve to meet the needs of a globalizing world, the government should continue to seek a healthy balance in the framework that concerns materials. Of crucial importance is the notion that an overly complex bureaucratic regime serves no interests effectively. Case studies show the need to streamline the complicated and intertwined legislative, regulatory and policy framework that now exists. Brief descriptions of some of the principal legal structures that affect the industry illustrate the government's varied legal interests in the materials realm.

Defense Production Act (DPA)

The Defense Production Act (DPA) of 1950 provides mechanisms for the President to meet material needs free markets might not provide. For example, Title I of the Act permits the President to prioritize certain contracts and orders to meet defense needs first, ensuring access to some raw materials. Title III of the Act is especially relevant to strategic materials as the DoD employs it to "create assured, affordable, and commercially viable production capabilities and capacities for items essential for national defense" (DDRE, n.d.).

Title III initiatives can substantially benefit government and selected industry players. By stimulating investment in targeted industries, Title III can affect supply, quality and costs for materials critical to national defense. These efforts can reduce U.S. dependency on foreign sources of supply. Title III activities also claim to lower defense acquisition and lifecycle costs (DDRE, n.d.). However, the government should employ judicious use of Title III authority to avoid unwarranted distortion of free-markets. While difficult, Title III analyses should objectively weigh the direct and indirect costs against other interests. In cases where the nation's strategic material needs override economic considerations – as has been found for beryllium – the DPA can be effective in securing domestic sources.

Foreign direct investment in strategic materials

Executive Order 11858 established the Committee on Foreign Investment in the United States (CFIUS) in 1975 to monitor and analyze impacts of foreign investment in the U.S. (U.S. Treasury OIA, n.d.). CFIUS authority expanded greatly in 1988 with the Exon-Florio Amendment to the DPA, which reflected growing Congressional interest in the national security impacts of foreign investment (Kimmitt, 2005).

Materials are often of special concern in CFIUS cases. According to a materials industry researcher, more than 20 percent of the foreign acquisitions evaluated by CFIUS between 1993 and 2003 concerned materials firms. Divestment through CFIUS decision has only occurred once, following the 1990 sale of MAMCO to China National Aero Technology Import Export Corp (Kimmitt, 2005). However, Committee activity has wider, more subtle effects.

It is impossible to assess the committee's true market power in the materials industry. However, having conducted over 1,500 total reviews to date, CFIUS has significantly shaped the acquisition environment. While some proposed mergers may pose legitimate harm to national security interests, critics have accused the Committee of arbitrary or politically motivated action (Weisman, 2006). Increasing scrutiny of CFIUS has produced bipartisan calls for reform to "introduce transparency, accountability and oversight to ensure public confidence that the deals approved by CFIUS do not pose a threat to national security" (Shelby, 2006). Improving processes for reviewing foreign investment and substantive trends could provide for more fair and balanced assessments of issues concerning materials, where economics and security interests can conflict.

Patent protections are increasingly difficult to enforce uniformly

Patent regulations have a significant impact on the materials industry. Protection of intellectual property (IP) is intended to encourage innovation. However, domestic and international patent systems are far from perfect. In particular, overseas enforcement of U.S. patent rights has become especially problematic. Estimates of U.S. losses due to IP theft cost U.S. companies up to $250 billion and as many as 750,000 jobs a year (USPTO, n.d.). Along with the bureaucratic burden of complex international patent processes, unenforceability of IP rights tends to inhibit materials innovation.

Fear of IP exploitation provided a common theme for participants in strategic materials industries. Some small businesses indicated a preference to retain tight control over proprietary processes for materials rather than expose trade secrets in patents. Another firm admitted to filing multiple patents for disinformation. Costs of pursuing patent infringement litigation reduced the utility of the existing patent structure according to industry participants interviewed during site visits.

Thus, many material firms and associated trade associations argue for simpler, stronger or more adaptable patent systems that are better suited for a global economy. Reforming the patent system to achieve these goals could encourage advances in leading-edge areas of the industry providing strategic materials, but would also require increased fees or some other budget offset to accomplish.

Berry Amendment

The 1941 Berry Amendment to the *National Defense Appropriations Act* has evolved significantly from its original intent of ensuring domestic production of military rations and

uniforms. Additional items – such as specialty metals for DoD – are now covered by the amendment, with significant effects on materials markets (Grasso, 2005).

While the Berry Amendment protects some parties, such as the domestic textile industry, other companies find compliance difficult. Hundreds of companies have reported to the DoD that they have used specialty metals from foreign producers in violation of the Berry Amendment (McCormack, 2006). The National Defense Industrial Association (NDIA) finds these restrictions particularly troublesome and recommends eliminating or relaxing them. The NDIA suggests instead that specialty metals should be covered only in the rare cases of "clearly demonstrated, critical national defense industrial base capability gaps" (NDIA, 2006, p. 8). As NDIA points out, Berry Amendment restrictions have imposed significant unintended compliance costs across the specialty metals supply chain with little associated benefit to the industrial base (NDIA, 2006).

National Industrial Security Program (NISP)

Access to classified information introduces additional concerns in managing strategic materials issues. While the NISP process clearly intersects with CFIUS issues, a differing focus in each venue produces complications that directly affect strategic materials markets. Globalization amplifies these concerns as companies become increasingly interconnected. In the last ten years, the number of foreign-owned firms with signed agreements to operate in accordance with the NISP has nearly doubled (McCarthy, 2006).

While the NISP does provide a framework for international industry participants to participate in national security procurements, the costs and complexity of this program can be daunting. All cleared facilities within the NISP must comply with stringent security requirements. Participating U.S. foreign-owned firms must build upon a baseline security program, incurring additional costs. Furthermore, these firms must establish mechanisms that place investors in a passive role. Security frameworks are an essential element of the materials industry, but these should enable, rather than discourage, international participation. Streamlining the current security processes would allow for efficient collaboration while satisfying national security concerns.

Export controls

The Export Controls regulatory framework also warrants reexamination as the materials industry adapts to a global marketplace. NDIA (2006) voices industry concerns that "the global marketplace has changed and continues to evolve in many directions … but, essentially, the world needs integrated economies to survive on a balanced basis" (p. 7).

The Departments of Commerce and State approach export control regulations from a different perspective, believing that national interests can be advanced through policy tools. While all parties can agree that features of the current framework are becoming outdated in an increasingly globalize economy, reform has been slow. NDIA (2005) highlights this stagnation by noting that "legislation to extend, repeal or significantly modify the Export Administration Act or the Arms Export Control Act has been introduced in Congress 35 times since 1991" to no avail (p. 8). While export control will continue to be a controversial issue, government efforts to adapt the current framework to reflect 21st century realities could ease significant tensions surrounding materials issues and allow companies to compete on more even terms (Adams, Cornu & James, 2001).

Lowering bureaucratic barriers that affect the materials industry

The many examples above demonstrate that current legal systems governing the materials industry are sometimes cumbersome and costly. While many restrictions serve important security purposes, efforts to streamline and adapt legal frameworks for the modern environment could substantially improve both the nation's economic competitiveness and security posture.

Materials Innovation – A Cornerstone of Military and Economic Strength

Innovation in materials produces strategic advantages for the nation; it is a key cross-cutting issue in this industry because of the need for continual improvement at every level of maturity. Simply stated, America's global competitiveness is at stake.

The forces of innovation manifest themselves across the spectrum of materials in a variety of ways. In mature materials, innovation can make production more efficient and lead to new product offerings. Improved labor productivity in the steel industry has led to a 5.7 percent yearly decline in man-hours required per ton since 1990 (Considine, n.d.). A trade association spokesman emphasized the continuing importance of innovation in the steel industry, where over 2,000 types of steel have been developed for applications demanding higher performance.

The innovative application of known (or newly developed) technologies becomes especially important in new systems where advanced materials help satisfy increasingly demanding capability requirements. The expanding use of REE alloys for military applications illustrates this trend in growth-sector materials.

To maintain its competitive edge in military and economic spheres, the U.S. must continue to expand its worldwide technological advantage through innovation. Benefits are manifest and highly practical. For example, polymers – originally discovered at DuPont more than 50 years ago – have evolved continually through innovation. Today polymers comprise the base material for all plastics and synthetic materials as well as advanced composite matrix materials and microscopic coatings for nanoparticles. The development of new composites illustrates similar innovative efforts as the physical properties of these materials can be tailored to create substitutes for existing materials. Such innovation in composites has allowed Boeing to design their 7E7 airliner with 50 percent composite and 20 percent aluminum by weight versus 12 percent composite and 50 percent aluminum for the 777 (Boeing, 2006).

Fundamental sources of innovation: Education and research

The wellspring of American innovation cannot be taken for granted. In particular, support for two critical sources of innovation – education and research – must be supported to foster future developments in materials of strategic interest. Although the U.S. currently enjoys a dominant position in the world, ominous trends point to decreased capacity to meet future materials needs when compared to other nations (TFFAI, 2005). Improved readiness will require continued and committed support for education and research, especially as European and East Asian nations increasingly challenge American technological leadership.

Educating the future workforce

Global competitiveness requires a well-educated, technically skilled workforce. Investments in education and training to develop this workforce also improve labor productivity. (Deller, 2005). A skilled and productive workforce will naturally attract direct foreign investment that

reinforces higher standards of living. However, educating a society to fulfill these pressing requirements is expensive, especially in the high-tech fields that support materials science (science, engineering and mathematics). Increasingly, American students are turning away from these fields; foreign students, meanwhile, seem to pursue them more aggressively (TFFAI, 2005).

Populating the materials workforce

Demographics will complicate the quest to populate the materials workforce. The Science and Engineering (S&E) workforce is graying rapidly, populated predominantly with baby-boomers over 40 years of age. Aggravating this demographic shift, the number of workforce S&E positions has grown at five times the overall rate of the U.S. civilian workforce over 25 years (from 1980 to 2005) while the number of citizens earning S&E degrees diminished (TFFAI, 2005).

To fill this void, a huge number of international S&E students have elected to remain in the U.S. following graduation from American institutions. During the next few decades, however, this international talent pool will likely evaporate as developing nations build domestic research capabilities by "luring native sons and daughters back home" (Monastersky, 2004). The impact on the entire field of materials science will be significant – with reverberations in economic and security spheres. Major shortages in high-tech workers will present significant challenges to American industry, academia, and defense agencies laboring to provide innovative future materials solutions.

Supporting materials innovation through research

An educated workforce cannot ensure innovation in materials science. The nation also must commit to research and development that makes use of this human capital. Declining trends in R&D investments suggest that U.S. dominance in science and technology may be at risk. Between 1995 and 2002, U.S. business investment in R&D declined from 2 percent of GDP to 1.87 percent. This contrasts with increased spending in other nations, such as Japan (where R&D investment rose from 2.12 percent to 2.32 percent) and China (where R&D investment has doubled from 0.6 to 1.2 percent of GDP) (TFFAI, 2005).

Strategic efforts to support materials innovation

Continued advances in materials are in the national interest, supporting both economic and defense needs. Assuring these advances requires an environment where innovation can flourish; continued innovation in materials will rest upon robust support for education and research. The government plays a key role in supporting basic research efforts as a public good, especially in this industry where long-term research is especially critical. Furthermore, emphasis on science and mathematics at all levels of education is critical to the nation's long-term competitiveness. Providing a framework where innovation can emerge through free markets should be a key tenet in the government's efforts to encourage development of a broad variety of materials with strategic impact.

Materials Substitutability: Do government efforts support free market forces?

A prime consideration in assessing a material's strategic value is the availability of potential substitutes, but the question of substitutability is rarely straightforward. Complicating factors

such as specifications, business risks, costs, global sourcing, fiscal environment and parochial biases can turn the most basic discussion of potential substitutes into a multivariate analysis of alternatives. These considerations are further complicated by the need to weigh countless circumstances and contingencies affecting strategic plans. Finally, the dual lenses – economic and military – used to examine a material's strategic value can compete with each other.

These many factors make a comprehensive objective assessment of substitute materials nearly impossible. An economist might argue that free markets would automatically lead to the selection of the most appropriate materials for given applications. However, while markets operate relatively efficiently for commodity-like materials, other features (often non-economic) of the materials industry can interfere with market forces and warrant special attention. Understanding barriers that prevent selection of more appropriate materials provides important context for any discussions of government policies intended to capitalize on the potential of substitute materials. Some specific areas where government influence affects the materials industry are requirements specification, reinforcement of cultural attachments to traditional materials and increasing pressures to cut government and industry research budgets.

Government specification of requirements

Existing methods of communicating government requirements tend to discourage the use of new materials. In particular, the military's "strictly defined procedures, processes, and manuals can conflict with the flexibility required" to introduce innovative materials (NRC, 2004, p. 11). These artificial limits also tend to focus R&D efforts away from potential substitutes for traditional materials. Better prioritization of R&D efforts will naturally emerge from an environment where specifications accommodate greater flexibility in materials selection.

Cultural attachment to traditional materials

Efforts to transition new materials from the laboratory to the field face significant obstacles in industry and academia beyond government specifications. Many engineers and developers are less comfortable with unconventional materials than with innovations in other disciplines. This tendency stems from difficulties engineers face in describing, understanding and integrating advanced materials into systems with existing tools. Therefore, selection of an alternative material can appear risky.

Tradition plays an important role in engineering. The field's professional norms are sufficiently strong that "introduction and acceptance of new technology often depend more on social, cultural, and historical factors than on technological merit" (NRC, 2004, p. 9). Because these factors stand in the way of improvements, efforts to increase familiarization with and confidence in advanced materials properties are essential. Improved databases, handbooks, models and standards for advanced materials would help overcome this institutional resistance to new materials. The NRC (2004) suggests that these tools should lead to "a comprehensive suite of materials modeling software and verified data" to accelerate the insertion of advanced materials (p. 4). The government can play a significant role in advancing the use of new materials for future applications by supporting the development of this next generation of engineering tools.

Budget pressures in an environment of risk aversion and cost cutting

Economic pressures to use traditional materials such as steel, aluminum and titanium can be compelling in industry. The desired properties of a particular substitute must outweigh the

many advantages traditional materials can offer such as predictable supply chains, established manufacturing processes and long-term proven reliability. Industry is often unable to justify the risk and costs inherent in introducing, proving and switching to a new material.

Additionally, extensive up-front research, development, test and evaluation (RDT&E) costs can dissuade even the most aggressive firms from designing products with unproven materials. While substitute materials often offer the promise of significantly better performance, return on investment in these technologies is not assured. Recouping development costs requires significant investment of time, effort and capital. Therefore, transitioning to new materials requires long-term fiscal commitment that industry may be unable – or unwilling – to provide.

Government support for basic research has historically provided a solution to industry's chicken and egg problem in developing substitute materials. During a site visit to a materials center of excellence, an advanced composites expert noted that industry is currently stuck waiting for a demand signal before ramping up production to accommodate more widespread (and economical) use of composites. Other sectors of the materials industry echo this concern. While government R&D can jump-start demand for exotic materials, decreasing government spending may erode the nation's current lead in developing and employing cutting-edge materials for defense applications.

Basic R&D provides the lifeblood that supports the development of substitute materials. As federal budgets shrink, increasing pressure to cut costs tends to result in the specification of low-risk solutions using established materials instead of promising new materials. Such an environment was apparent in overseas government research facilities, where tight budgets appeared to limit innovative thinking due to significant concerns regarding cost to benefit ratios for new materials.

There is no one-size-fits-all approach for R&D funding. Instead, research spending should seek to balance a conservative "business case analysis" approach with aggressive efforts to find optimal solutions. Currently, materials research tends to look toward short-term solutions instead of exploring potential substitutes that could save money in the end. Properly used, government technical expertise can help guide constructive dialogue among stakeholders to encourage the emergence of cost-effective material substitutes for appropriate applications.

Cost and availability are important considerations in obtaining an item or service in all walks of life and in every industry sector. Decisions on materials substitutability should turn on these factors rather than cultural resistance and institutional fear. This study of the materials industry found very few examples of "unsubstitutable" strategic materials. However, ensuring the continued development and improvement of new substitutes requires government involvement to shape R&D and manufacturing technology efforts if the industry is to meet America's evolving needs.

Conclusions on Meeting Strategic Needs with Materials

While materials firms face many challenges, the industry that provides materials with strategic value for the nation remains relatively healthy. Appreciation for the industry's readiness to meet the country's needs requires a broad perspective, one that considers the vast diversity of participating firms and products as well as trends that affect materials markets such as globalization, substitution, and innovation. A broad approach helps avoid the common pitfall of overemphasizing the strategic value of a particular material, process or technology. While many government actions are instrumental to the material industry's ability to support

strategic needs, perspectives that are too narrow may drive counterproductive government interventions.

This study identified a variety of government roles specific to each industry lifecycle stage. For mature materials producers, the government must understand and appreciate potential impacts of material shortages, especially as this sector's infrastructure ages. However, calls for increased government support warrant healthy skepticism to avoid unnecessary distortions of free-markets. Continued emphasis of free-market principles for both domestic and international participants in mature materials markets will help prevent government from subsidizing inefficient or unproductive firms.

Government involvement is somewhat more important for materials in growth-stage markets because its efforts can reduce barriers that prevent wider acceptance of new materials. Program funding provides the most direct mechanism for insertion of new materials into systems. However, indirect efforts such as improved modeling and simulation, materials data standardization and enhanced manufacturing technology are increasingly important enablers for technology transition. Government also bears the responsibility of monitoring these growth stage materials markets for potential shortages that could result from interruptions in supply of raw materials.

Government's most important role in this industry is ensuring the development of breakthrough materials to meet the nation's strategic needs. The promise of materials will emerge only through far-sighted R&D efforts that can overcome show-stopping challenges, such as extended development timeframes and declining research investments. Because budget pressures will likely preclude additional materials R&D funding, prioritization of existing efforts is essential to ensure continued development in the most promising and important materials specialties.

Across the broad spectrum of the materials industry, more effective collaboration between industry, government and academia could improve the industry's ability to cope with a variety of cross-cutting concerns. For example, streamlining the legislative, regulatory and policy framework that governs the industry could significantly improve its efficiency. Additionally, increased support for education and research throughout American society would provide for continued innovation in materials science. Furthermore, increased willingness to accept and use substitutes for established materials could reduce market pressures that result in inefficiencies. While these issues suggest areas for improvement, none offers a compelling case that the U.S. government must act aggressively to ensure the materials industry can meet the nation's strategic needs.

An examination of the strategic materials industry uncovers little evidence of market failures warranting more assertive government intervention. In contrast, some examples of government involvement appear heavy-handed or inefficient. Government's focus in this industry should be to support a fair and stable framework within which market forces principally drive materials firms' decisions. Direct government involvement in this industry should be limited to addressing strategic needs that market forces cannot satisfy.

REFERENCES

Adams, G., Cornu, C., and James, A. (2001). Between Cooperation and Competition: the Transatlantic Defence Market. [Chaillot Paper 44]. Paris, France. Retrieved May 2, 2006 from www.iss-eu.org/chaillot/chai44e.pdf

American Iron and Steel Institute (AISI). (2005). *AISI Market Development Report 2004-2005*. Washington, DC: AISI

Baumol, W.J. & Blinder, A.S. (2006). *Economics: Principles and Policy* (10th ed). USA: Thompson South-Western.

Boeing Company. (2006). 787 Dreamliner. [Company Online Fact Sheet]. Retrieved May 10, 2006 from http://www.boeing.com/commercial/787family/programfacts.html

Bush, G. W. (2002). Steel Products Proclamation to Facilitate Positive Adjustment to Competition from Imports of Certain Steel Products. [White House Press Release of March 5, 2002]. Retrieved May 21, 2006 from http://www.whitehouse.gov/news/releases/2002/03/20020305-7.html

Chairman of the Joint Chiefs of Staff (CJCS). (2004). *The National Military Strategy (NMS) of the United States of America: A Strategy for Today; A Vision for Tomorrow*. Retrieved February 15, 2006 from http://www.defenselink.mil/news/Mar2005/d20050318nms.pdf

Cientifica. (2006). VCs to Nanotech: Don't Call Us! [Online whitepaper]. Retrieved May 17, 2006 from http://www.cientifica.com/www/details.php?id=341

Considine, T.J. (n.d.). The Transformation of the North American Steel Industry: Drivers, Prospects and Vulnerabilities [undated press release supplement from the American Iron and Steel Institute (AISI)]. Retrieved May 5, 2006 from http://www.steel.org/AM/Template.cfm?Section=Home&CONTENTFILEID=1452&TEMPLATE=/CM/ContentDisplay.cfm

Council of Economic Advisors (CEA). (2005). The Annual Report of the Council of Economic Advisors. In *Economic Report of the President*. (pp. 8-186). Washington D.C.: U.S. Government Printing Office.

Deller, S.D. (2005). Labor Productivity, Why Should We Care? *Community Economics Newsletter (341).* Madison, WI: University of Wisconsin. Retrieved May 10, 2006 from http://aae.wisc.edu/pubs/cenews/docs/ce341.pdf

DeNoon, D.P.H. (2001). Economics and National Security. In R.L. Kuger & E.L. Frost (Eds.) *The Global Century: Globalization and National Security*. Washington, DC: National Defense University Press.

Department of Defense (DoD). (2006). *2005 Report to Congress on National Defense Stockpile Requirements*. [Report transmitted to the Speaker of the House of Representatives on March, 31 2006]. Washington, DC: Office of the Undersecretary of Defense for Acquisition, Technology and Logistics (USD(AT&L).

Deputy Undersecretary of Defense for Industrial Policy (DUSD(IP)). (2003). *Transforming the Defense Industrial Base: A Roadmap*. Washington, DC: ODUSD(IP). Retrieved May 22, 2006, from http://www.acq.osd.mil/ip/docs/transforming_the_defense_ind_base-report_only.pdf

Director, Defense Research and Engineering (DDRE). (n.d.) *Defense Production Act (DPA)* Title III Homepage. Retrieved on May 2, 2006 from http://www.acq.osd.mil/ott/dpatitle3/program.htm

Echternacht, K. L. (2005). The National Defense Stockpile: Unresponsive for the New Global, Transnational Environment. [Student Essay from Strategic Materials Industry Study 2005, available from Dr. Sylvia Babus, Industrial College of the Armed Forces (ICAF) Faculty]. Washington DC: ICAF.

General Accounting Office (GAO, now Government Accountability Office). (2001). *National Defense Stockpile: Improved Financial Plan Needed to Enhance Decision-Making*. [Report GAO-01-17]. Washington, DC: GAO.

General Accounting Office (GAO, now Government Accountability Office). (2004). *Defense Acquisitions: Assessments of Major Weapons Programs*. [Report GAO-04-248]. Washington, DC: GAO.

Government Accountability Office (GAO). (2005). *Defense trade: implementation of Exon-Florio*. [Report of the Government Accountability Office, number GAO-06-135T]. Retrieved on May 11, 2006 from http://banking.senate.gov/_files/d06135t.pdf

Grasso, V.B. (2005). *The Berry Amendment: Requiring Defense Procurement to Come From Domestic Sources*. [CRS report RL31236]. Washington DC: Congressional Research Service (CRS). Retrieved on May 11, 2006 from http://www.fas.org/sgp/crs/natsec/RL31236.pdf

Hamre, J. (2000). Testimony of Deputy Secretary of Defense John Hamre before the Senate Armed Services Committee, February 28, 2000. Retrieved May 17, 2006 from http://armed-services.senate.gov/statemnt/2000/000228jh.pdf

Hedrick, J.B., (2004). Minerals Yearbook: Rare Earths. *U.S. Geological Survey Minerals Yearbook*. Retrieved on March 10, 2006 from: http://minerals.usgs.gov/minerals/pubs/commodity/rare_earths/rareemyb04.pdf

Kennedy, P. (1989). *The Rise and Fall of the Great Powers*. New York: Vintage Books. (Original work published 1987).

Kimmitt, R. (2005, October 20). Testimony before the United States Senate Committee on Banking, Housing and Urban Affairs. Retrieved April 8, 2005 from http://www.treas.gov/press/releases/js2981.htm

Lorell, M.A., Lowell, J., Moore, R.M., Greenfield, V. and Vlachos, K. (2001).*Going Global? U.S. Government Policy and the Defense Aerospace Industry*. Santa Monica, CA: RAND.

Marshall, M.L., Coffey, T., Saalfeld, F.E., Colwell, R.R, (2004). *The Science and Engineering Workforce and National Security. Defense Horizons (39)*. Washington, DC: Center for Technology and National Security Policy (CTNSP).

Max-Planck-Gesellschaft (MPG) [Max Planck Society]. (2001). *European White Book on Fundamental Research in Materials Science*. Stuttgart, Germany: Max Planck Institut Fur Metallforschung. Retrieved May 11, 2006 from http://www.mpg.de/pdf/europeanWhiteBook/wb_materials_010_015.pdf

McCarthy, E. (2006, March 18). Foreign firms a mainstay of pentagon contracting. *The Washington Post*, p. D1. Retrieved May 11, 2006 from http://www.washingtonpost.com/wp-dyn/content/article/2006/03/17/AR2006031702121.html?nav=rss_technology/techpolicy

McCormack, R. (2006, May 2). Hundreds of defense contractors are using illegal foreign metals in weapons systems. *Manufacturing & Technology News*. p. 3. Retrieved May 11, 2006, from http://ebird.afis.mil/ebfiles/e20060504432776.html

McHale, J. (2004). Nanotechnology; the revolution has begun. *Military & Aerospace Electronics. 15(* 9). Pg. 21. Retrieved March 14, 2006 from http://exproxy6.ndu.edu/login?url=http://search.epnet.com/login.aspx?direct=true&db=afh&an=14493593

McNight, S. (2006). [Notes from study members' interview with Dr. Steven McNight, Chief of Army Research Lab's (ARL) Materials Division, conducted March 30, 2006].

Merrill, S.A. (Ed.). (2001). *Trends in Federal Support of Research and Graduate Education*. Washington DC: National Academy Press.

Michaels, D. (2006, May 9). Airbus seals titanium-supply pacts valued at $1.4B: Rising use of metal in jets fuels scramble to secure materials. *The Wall Street Journal Europe XXIV(68)*, p. 3. Brussels, Belgium: Dow Jones & Company.

Monastersky, R. (July 9, 2004). Is There a Science Crisis? Maybe not. *The Chronicle of Higher Learning, 50*(44), pg. A-10. Retrieved May 11, 2006 from http://ezproxy6.ndu.edu/login?url=http://proquest.umi.com/pdqweb?did=676283551&sid=2&Fmt=3&clientId=3921&RQT=309&VName=PQD

Mraz, S.J. (2005, November 17). Nanowaste: The Next Big Threat? *Machine Design. 77*(22). Pp. 46-53.

National Defense Industrial Association (NDIA). (2005). *Top Issues 2005*. Retrieved May 10, 2006 from http://www.ndia.org/Content/NavigationMenu/Advocacy/Policy/PDFs28/05TopIssues.pdf

National Defense Industrial Association (NDIA). (2006). *Top Issues 2006*. Retrieved May 10, 2006 from http://www.ndia.org/Content/NavigationMenu/Advocacy/Policy/PDFs28/NDIATopIssues06.pdf

National Nanotechnology Initiative (NNI). (2005). *The National Nanotechnology Initiative: Research and Development Leading to a Revolution in Technology and Industry* [Supplement to the President's FY 2006 Budget]. Retrieved May 18, 2006 from http://www.nano.gov/NNI_06Budget.pdf

National Research Council (NRC) of the National Academies. (2003). *Materials Research to Meet 21st Century Defense Needs.* Washington, DC: The National Academies Press.

National Research Council (NRC) of the National Academies. (2004). *Accelerating Technology Transition: Bridging the Valley of Death for Materials and Processes in Defense Systems.* Washington, DC: The National Academies Press. Retrieved May 11. 2006 from http://darwin.nap.edu/html/accel-tech/0309093171.pdf

National Research Council (NRC) of the National Academies. (2005). *Globalization of Materials R&D: Time for a National Strategy.* Washington, DC: The National Academies Press.

New York Times. (2000, December 27). Company News: Aluminum Smelter to Reduce Output and Sell Power. New York, NY: New York Times Archives. Retrieved May 14, 2006 from http://query.nytimes.com/gst/fullpage.html?res=9A04EFDE1138F934A15751C1A9669C8B63

Office of the Secretary of Defense (OSD). (2005). *The National Defense Strategy (NDS) of the United States of America*. Retrieved February 15, 2006 from http://www.defenselink.mil/news/Mar2005/d20050318nds1.pdf

Office of the Secretary of Defense (OSD). (2006). *Quadrennial Defense Review (QDR) Report*. Retrieved March 14, 2006 from http://www.defenselink.mil/qdr/report/Report20060203.pdf

Office of Technology Assessment (OTA). (1985). *Strategic Materials: Technologies to Reduce U.S. Import Vulnerability*. Washington, DC: U.S. Congress, Office of Technology Assessment, OTA-ITE-248. Retrieved May 17, 2006 from http://govinfo.library.unt.edu/ota/Ota_4/DATA/1985/8525.PDF

Porter, M.E. (1980). *Competitive Strategy: Techniques for Analyzing Industries and Competitors*. New York, NY: The Free Press.

Schacht, W. (2005). *Industrial Competitiveness and Technological Advancement: Debate Over Government Policy*. Congressional Research Service (CRS) Issue Brief for Congress IB91132. Washington, DC: CRS.

Schafrik, R. and Sprague, R. (2004). Saga of Gas Turbine Materials. Advanced Materials & Processes. [Reprint of four-part series from March, April, May, June 2004 issues]. Cincinnati, OH: General Electric Reprint.

Shelby, R.C. (2006, March 29). Takeover Makeover. *Wall Street Journal*, p. A18. Retrieved May 10, 2006 from http://www.ofii.org/newsroom/news/032906wsj.html

Task Force on the Future of American Innovation (TFFAI). (2005). *The Knowledge Economy: Is the United States Losing its Competitive Edge?* Retrieved November 3, 2005, from http://www.futureofinnovation.org/PDF/Benchmarks.pdf

Taylor, J. and Van Doren, P. (2005). The Case against the Strategic Petroleum Reserve. *Policy Analysis No. 555*. Washington, DC: The Cato Institute. Retrieved May 23, 2006 from http://www.cato.org/pubs/pas/pa555.pdf

United States Department of the Treasury Office of International Affairs (U.S. Treasury OIA). (n.d.). [History and background information on the Committee on Foreign Investments in the United States (CFIUS)]. Retrieved on May 11, 2006 from http://www.ustreas.gov/offices/international-affairs/exon-florio/

United States Geological Survey (USGS). (2006). *Mineral Commodities Summaries 2006*. U.S. Government Printing Office, Washington D.C. Retrieved on March 10, 2006 from http://minerals.usgs.gov/minerals/pubs/mcs/2006/mcs2006.pdf

United States Patent and Trademark Office (USPTO) of the Department of Commerce. (n.d.). Frequently Asked Questions (FAQ) about USPTO. Retrieved on May 14, 2006 from http://ftp.uspto.gov/smallbusiness/pdfs/USPTOSmallBusinessCampaignFAQ.pdf

Weisman, J. (2006, March 11). Port Deal's Political Fallout Not Over: House GOP Drafting Bill to Require Hill Oversight of Foreign Acquisitions. *The Washington Post*. P. A03. Washington, DC: The Washington Post Company. Retrieved May 14, 2006 from http://www.washingtonpost.com/wp-dyn/content/article/2006/03/10/AR2006031000749_pf.html

Weiss R. (2006a, January 11). Stricter Nanotechnology Laws Are Urged. *The Washington Post*. Pg. A.02. Washington DC: The Washington Post Company.

Weiss, R. (2006b, April 7). Nanotech Product Recalled in Germany. *The Washington Post*. Pg. A.02. Washington, DC: The Washington Post Company.